Neutral and charged pion production in the S-matrix approach

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Retardation effects and off-shell dependencies of the rescattering operator in neutral pion production were recently investigated[1] within the framework of time-ordered perturbation theory (TOPT). Various approximations to the result obtained from TOPT were analysed. The central problem underlying this study is that the final- and initial-state interaction diagrams do not define a *single* effective operator. Since in the time-ordered diagrams energy is not conserved at individual vertices, each of these diagrams defines a different off-energy shell extension of the pion rescattering amplitude. This problem is not present in the S-matrix derivation of the effective rescattering operator (for definition of the S-matrix approach and detailed discussion see Ref. [1] and references therein).

In this work, we applied this approach to charged and neutral pion production in pp collisions, in which the spin/isospin channels filter differently the rescattering mechanism. As in Ref.[1], the chiral perturbation theory rescattering amplitude[2] is employed. The contributions from the single-nucleon (so-called, impulse approximation: IA), Z-diagrams and Δ-isobar mechanisms are also included.

The contributions of all the mechanisms considered are shown on Fig. 1. For the reaction $pp \to pp\pi^0$ the IA term (dashed line) is suppressed. On the other hand, the IA and rescattering mechanisms (dotted line), which interfere destructively, are clearly not enough to describe the data, and the Z-diagrams (dashed-dotted line) are found to be very important in reproducing the cross section. The Δ-isobar, when included explicitly (solid line) plays a significant role, even at energies close to threshold, improving the description of the data.

The convergence of the partial wave series of Table 1 is shown on Fig. 2. As expected, the contributions with $J > 0$ start to play their role only about 20MeV above threshold. Including all contributions with J up to $J = 3$ yields a reasonably converged results. The effect of the potential used for distorting the NN final and initial states is studied on Fig. 3. Although the cross sections for the first channel considered differ for the Bonn B and CD Bonn potential (dotted and dashed-line, respectively), and this deviation is increasing with T_{lab}, when all the contributions to $J = 0$ are included (dashed-dotted vs. solid line), the results for the cross section for both potentials are very close.

For the reaction $pn \to pp\pi^-$, the convergence rate of the partial wave series is not as uniform as for $pp \to pp\pi^0$ (Fig. 4). Although $J = 0$ is enough to describe

$(NN)_i$	$(NN)_f\, l'$	S	L	J	S'	L'	j'	l'
$^3P_0$	$(^1S_0)\, s$	1	1	0	0	0	0	0
$^1S_0$	$(^3P_0)\, s$	0	0	0	1	1	0	0
$^3P_0$	$(^3P_1)\, p$	1	1	0	1	1	1	1
$^3P_1$	$(^3P_0)\, p$	1	1	1	1	1	0	1
$^3P_1$	$(^3P_2)\, p$	1	1	1	1	1	2	1
$^3P_1$	$(^3P_1)\, p$	1	1	1	1	1	1	1
$^3P_2$	$(^3P_1)\, p$	1	1	2	1	1	1	1
$^3F_2$	$(^3P_1)\, p$	1	3	2	1	1	1	1
$^1D_2$	$(^3P_2)\, s$	0	2	2	1	1	2	0
$^3P_2$	$(^3P_2)\, p$	1	1	2	1	1	2	1
$^3F_2$	$(^3P_2)\, p$	1	3	2	1	1	2	1
$^3F_3$	$(^3P_2)\, p$	1	3	3	1	1	2	1

Table 1: The lowest partial waves for $pp \to pp\pi^0$. $S(S')$, $L(L')$ and $J(j')$ are the spin, the orbital momentum and the total angular momentum of the initial(final) NN pair, respectively. l' is the angular momentum of the pion relative to the final NN pair.

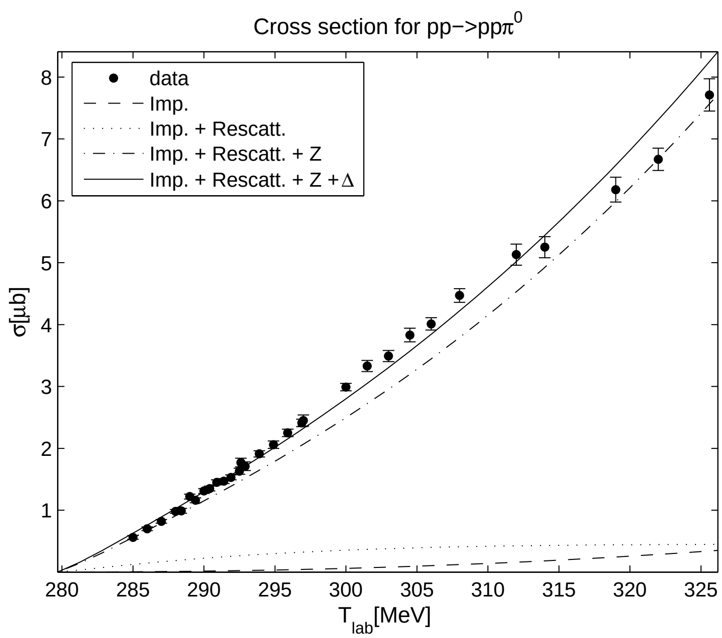

Figure 1: Various contributions to the cross section of $pp \to pp\pi^0$. The NN interaction is described by the Bonn B potential. The data points are from Ref.[3]

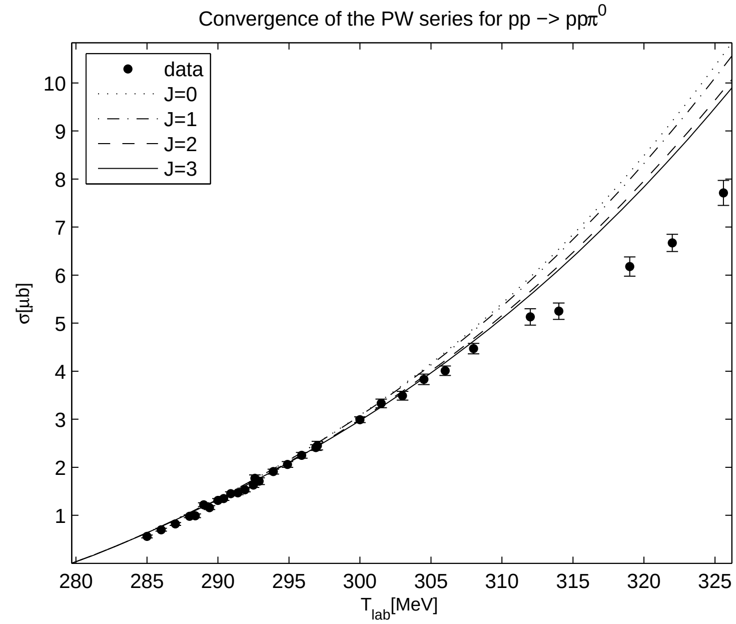

Figure 2: Cross section for $pp \to pp\pi^0$. The dotted, dashed-dotted, dashed and solid line correspond to the cross section for the Bonn B NN potential and to all contributions up to $J = 0, 1, 2, 3$, respectively.

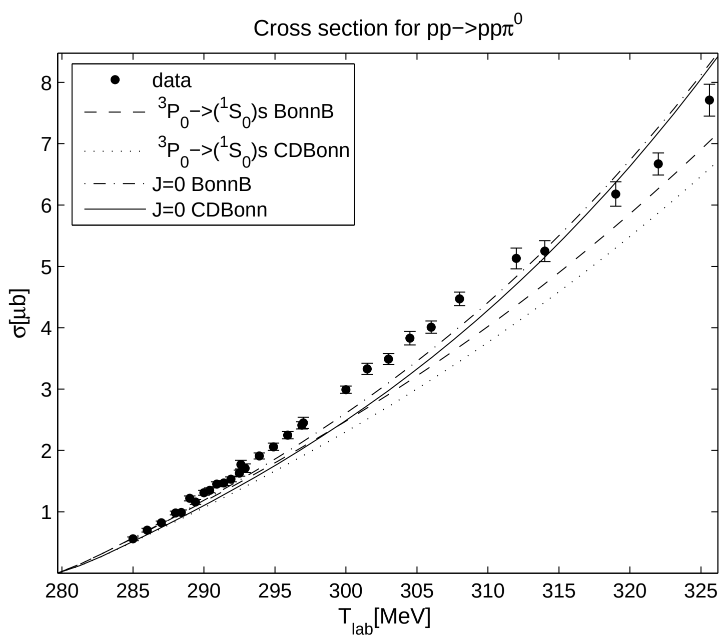

Figure 3: Effect of the NN interaction on the convergence of the partial wave series for $pp \to pp\pi^0$. The dotted(dashed) line corresponds to the cross section for the first channel considered, ${}^3P_0 \to ({}^1S_0)\, s$ for the Bonn B (CD Bonn) potential. The solid(dashed-dotted) line corresponds to the contribution up to $J = 0$ for the Bonn B (CD Bonn) potential. The Δ-isobar is not included.

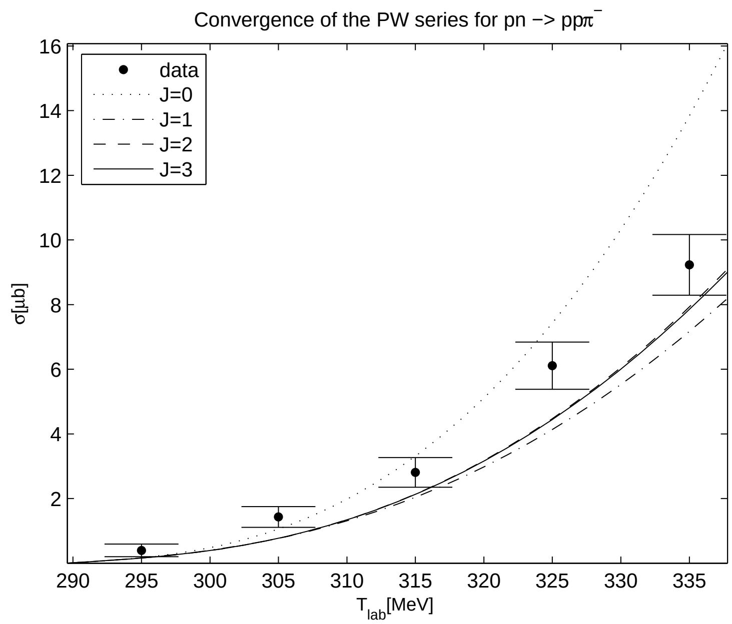

Figure 4: The same of Fig. 2, but for $pn \rightarrow pp\pi^-$. The data points are from Ref. [4].

the data close to threshold, the contributions with higher J included underestimate the cross section, in particular for larger T_{lab}. The origin of this discrepancy may be the non-inclusion of the coupled $N\Delta$ channels, which play for sure an important role and must be included in a further analysis.

To sum it up: the S-matrix approach is successful in describing the cross section for π^0 and π^- production. For both reactions, the convergence of the partial wave series is quite satisfactory and $J = 0$ is enough to describe the data close to threshold. If one includes all contributions with $J = 0$ (not just a single dominant channel), the results do not depend much on the choice of the NN interaction. For charged pion production, in which the Δ is known to play a decisive role (in particular for π^+), a complete coupled-channel $N\Delta$ calculation will be needed to describe the data. Also, the S-matrix approach should be tested by more sensitive polarisation observables.
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References

[1] V. Malafaia, J. Adam and M. T. Pena, Phys. Rev. C **71**, 034002 (2005).

[2] B.-Y. Park, *et al.*, Phys. Rev. **C53**, 1519 (1996).

[3] H. O. Meyer *et al.*, Nucl. Phys. A **539**, 633 (1992).

[4] M. G. Bachman *et al.*, Phys. Rev. C **52**, 495 (1995).

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